Synthesis and FTIR Analysis of Cd Doped Nano Ni - Aluminates

Ammara Yaseen a, Adnan Yasin b, Akasha Saleem c, Faqeer Muhammad a, Rafia Ismail a, Muhammad Ismaeel d, Ihsan Ali e, Zarwali Khan c, Muhammad Usman f, Muhammad Ramzan g, Tayyaba Shabir h, Zobia Yaseen c and Nasir Abbas i

a Institute of Chemical Sciences, Bahauddin Zakariya University, Multan 60800, Pakistan.
b Department of Chemistry, University of Education, Lahore (Vehari campus), Vehari, Punjab, Pakistan.
c Department of Chemistry, University of Agriculture, Faisalabad 38040, Pakistan.
d Department of Mathematics and Statistics, NCBA & E Lahore, Multan Sub-Campus Multan, Pakistan.
e Higher Education Department (HED), Govt. of Punjab, Lahore 54000, Pakistan.
f Department of Chemistry, Govt. Graduate College, Shor Kot City 35050, Punjab, Pakistan.
g Department of Chemistry, Govt. College University, Faisalabad 38000, Pakistan.
h Department of Chemistry, Ghazi University, Dera Ghazi Khan 32200, Pakistan.
i Department of Chemistry, Quaid-e-Azam University, Islamabad 45320, Pakistan.

Authors’ contributions
This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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*Corresponding author: E-mail: mhrub@gmail.com;
ABSTRACT

Nano Ni – Aluminates (Ni\textsubscript{0.5}Fe\textsubscript{0.5}Al\textsubscript{2}O\textsubscript{4}) and Cd Doped Nano Ni – Aluminates (Ni\textsubscript{0.5}Fe\textsubscript{0.5}Al\textsubscript{x}Cd\textsubscript{0.5}O\textsubscript{4}) where x = 0.2, 0.4, 0.6 and 0.8 were synthesized by co-precipitation method. Ammonium hydroxide was used as precipitating agent. The samples were characterized using Fourier transform infrared spectroscopy. FTIR spectrum for each unannealed sample of Ni\textsubscript{0.5}Fe\textsubscript{0.5}Al\textsubscript{2}O\textsubscript{4} and Ni\textsubscript{0.5}Fe\textsubscript{0.5}Al\textsubscript{x}Cd\textsubscript{0.5}O\textsubscript{4} exhibit a broad band near 3450 cm\textsuperscript{-1} due to –OH stretching vibration of free hydrogen bonded hydroxyl group and a second typical absorption band at 1620 cm\textsuperscript{-1} resulting from deformative vibration of water molecules. Spectra for samples after annealing show peaks in the range of 900-450 cm\textsuperscript{-1} and 850-500 cm\textsuperscript{-1} showing presence of Al-O and Ni-O bonds respectively thus confirm the formation of metal oxides bonds while no peak was observed for –OH bond. A peak around 420 cm\textsuperscript{-1} is assigned to Cd-O bond.

Keywords: Nano-ni aluminates; Cd doped nano ni-aluminates; co-precipitation; fourier transform infrared spectroscopy.

1. INTRODUCTION

Nanotechnology is a broad concept which provides wide range of exceptional cases to alter the world. This technology deals with particles having dimensions at a length scale of 1 / 100 million of a meter [1]. This specific field allows molecular diagnosis at nanoscale. Nanotechnology integrates chemistry, biology and material sciences to create novel properties that can be exploited to attain new market opportunities and challenges. Industrial perspectives cover electronics, biomedical, performance materials and consumer products. Nanotechnology offers applications in cancer therapy [2], dental materials [3], optics, DNA engineering, high performance textiles, catalysis and sports.

Materials having internal or space surface structure in the nanoscale are represented as nanomaterials [4]. Nanomaterials complexity provides a diversity of functions to products [5]. Nanoparticles are fundamental components of nanomaterials. Nanomaterials are divided into various categories depending on dimension, size, morphological parameters, structure and basic composition. Metal based nanoparticles are synthesized from metals to nanometric sizes using constructive or destructive methods [6]. Metal NPs include silver(Ag), gold(Au), Iron(Fe), aluminium(Al), cadmium(Cd), cobalt(Co), copper(Cu), lead(Pb). Reduction of size of particles to nanometer scale alters the band gap, creating discrete energy levels with the large number of active atoms due to greater separation among the atomic-coordinates and un-saturated points. These metal based nanomaterials have biomedical applications [7] such as catheters implants, medical delivery system, tissue engineering and dentistry.

Various metal oxides (Fe\textsubscript{2}O\textsubscript{3}, Al\textsubscript{2}O\textsubscript{3}, TiO\textsubscript{2}, ZnO and SiO\textsubscript{2}) can be prepared using sol-gel or hydrothermal method [8]. Variation in different morphological characteristics alter band gap energies of the materials. Modification of surface can be done using a polymeric precursor chain, coupling reagents or doped with metallic ionic species, epoxies, amines, thiols and anionic compounds. Metal oxide nanoparticles have attractive applications in the field of catalysis [9], sensors, electronics, environmental remediation, biotechnology, magnetic fluids, data storage devices, and magnetic resonance imaging [10].

Semiconductor nanomaterials are made up of different compounds of various groups including IV A group (SiO\textsubscript{2}) [11]. These nanomaterials have 4ev bandgap energy [11]. Unique quantum nature of these nanomaterials [12] enhances their physical and chemical properties. They have many applications including transparent conductive contact, solar cell, luminescent devices, laser diodes and UV-lasers. Nanomaterials can be classified according to their dimensionality [13]. This classification mode depends upon size of nanoparticles which range from 1 to 100nm in one dimension. 0D nanomaterials have size below 100 nm [14], with all their dimensions in nanoscale. Spherical, cube, nano-rod, polygon, hollow sphere, metal and core shell nanomaterials are included in this group. Quantum dots are well known member of this group. QDs are semiconductor [15], metal oxides having 1000 to 100,000 atoms in an extended solid structure. They have enhanced electronic, optical, magnetic and catalytic properties. 1D nanomaterials [16] have at least single dimension which is not in nanoscale but remaining two dimensions in nanometric range. One dimensional nanomaterials [17] include metallic, polymeric, ceramic, nanotubes and
nano-rod filaments. Nanowires and nanofibers are well known examples of this group. Nanowires have single crystal structure with a diameter of a few tens of nanometers [18]. These are widely used in electronic devices as nano-interconnector for transport of electrons.

2D nanomaterials [19] have at least single dimension of nanometric range but remaining two dimensions are not in nano scale. These involve single layered, multilayered crystals, amorphous thin layered surfaces, nano plates and nanocoatings. Layered silicates are novel field within nanotechnology for nanoscale engineering of surfaces and layers with exceptional functionalities and physical effects. 3D nanomaterials [20] include many dimensions above 100 nanometer. Examples include foam, fiber, CNTs, fullerene, polycrystals, layered skeletons, honeycombs structures, pillars.

Nano Crystalline Spinels [21] are Face centered cubic close packing of anionic particles possessing holes provide the special structure of nano crystalline spinel. These holes are partially filled by cations particles. They have molecular formula (A⁴⁺)₂[B³⁺]₂O₄. While A⁴⁺ and B³⁺ are the divalent and trivalent cations at tetrahedral (A) and octahedral (B) interstitial sites of the face centered cubic aroused by O²⁻ ions [22]. Different parameters of these oxides depend upon the type and positions of these cations among the two interstitial sites. Ionic bond is present in all oxide spinel. Calcining temperature is the controlling factor for different types of spinels. Based on distribution of cations among two interstitial sites, nanocrystalline spinels are divided into following types of Normal spinel, Inverse spinel, Random spinel [23]. The main aspect of normal spinel is the presence of A⁴⁺ in tetrahedral position and B³⁺ in octahedral position [24]. Example includes CoAl₂O₄. This double oxide spinel finds its applications in ceramics, glasses, paints and T.V tubes. In Inverse Spinel, half of trivalent ion preferentially fill the tetrahedral sites (A site) and other half occupies the octahedral sites (B site). Example includes NiAl₂O₄ and can be represent as: (Al³⁺)₄[Ni²⁺Al³⁺]₂O₄ where A is tetrahedral site and B is octahedral site [25]. Nickel aluminae attract the research interest because of excellent thermal stability [26], high mechanical resistance, hydrophobicity and lower surface acidity. In random spinel, tetrahedral and octahedral interstitial sites are randomly occupied by the two metallic ions (A⁴⁺, B³⁺). Example includes MgFe₂O₄.

Nanomaterials are of special interest because of their novel applications in different field of sciences [27]. Surface modification with various type of functional groups and active agents create definite active site thus enhancing surface topography. Surface interactions including noncovalent, covalent, electrostatic Vander walls or hydrogen bonding made nanomaterials functionalized for different applications and fields. Nanoparticles serve as a bridge between bulk material and atomic or molecular structures. Novel properties of nanoparticles are governed by their significantly smaller size. Size controls fundamental electric, magnetic, mechanical and thermal properties without changing their chemical composition. There are several methods for synthesis of nanoparticles. Co-precipitation method involves nucleation, growth, coarsening and agglomeration to take place at the same time of chemical reaction [28]. Insoluble precipitates of product are formed owing to high supersaturation. Coarsening and agglomeration affect size, shape and properties of particles. This is an important route for synthesis of metals, oxides and metal chalconides with easy and rapid precipitation without any organic reagent at a relatively low temperature. Nanoparticles with desired shape, size and morphology can be obtained. This method is useful to synthesize super ionic materials, microporous crystals, chemical sensor products, electronics, ceramics, magnetic and luminescence items. This is a green chemistry approach for fabrication of porous metal oxide spheres [29]. Sufficient templating is obtained for providing monodispersed, nonagglomerated porous spheres. Fe and Al₂O₃ sols result in cracked spheres having sufficient oxide material on surface while in case of Indium oxide, a hollow broken shell is obtained which are more active photocatalyst than Degussa P₂₅ titanita (a commercial standard). Mesoporous silica films can serve as template for gold and platinum nanoparticles having uniform size distribution [30]. Biological synthesis interconnects nanotechnology and biotechnology to synthesize large variety of NPs. Diversity of biological materials bring the method important from economical point of view. Synthesis of Au, Ag, Au-Ag alloys, Se, Te, Pt, Pd, Si, Ti, Zr, QDs nanoparticles using bacteria, algae, fungi, yeast and viruses is commonly employed nowadays. This method is not commercially important owing to slow rate of synthesis having poly dispersed nanoparticles. Photobiological method provides sufficient yield with improved properties [31].
2. METHODOLOGY

2.1 Solution

First of all, 0.1M stock solution of nickel nitrate, 0.1M stock solution of Iron (III) nitrate, 0.2M stock solution of aluminium nitrate and 5M stock solution of ammonium hydroxide were prepared for synthesis of undoped and cadmium doped nano aluminates. Ammonium hydroxide stock solution serves as a precipitating agent for precipitate formation.

Calculation for stock solutions is listed below:

Table 1. Stock solutions

<table>
<thead>
<tr>
<th>Chemical formula of compound</th>
<th>Molarity</th>
<th>Mass of metal salt (g) in 100mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni(NO₃)₂.6H₂O</td>
<td>0.1</td>
<td>2.90</td>
</tr>
<tr>
<td>Fe(NO₃)₃.9H₂O</td>
<td>0.1</td>
<td>4.04</td>
</tr>
<tr>
<td>Al(NO₃)₃.9H₂O</td>
<td>0.2</td>
<td>7.50</td>
</tr>
</tbody>
</table>

2.2 Preparation of Undoped and Cd-Doped Nano Ni-aluminates

To prepare undoped and cadmium doped nano aluminates, concentration of nickel nitrate and iron (III)nitrate were kept same while that of aluminium nitrate was different as follows:

Ni₀.₅Fe₀.₅AlₓCdₓO₄

There are following formulas for cadmium doped nano aluminates:

- Ni₀.₅Fe₀.₅Al₁.₈Cd₀.₂O₄
- Ni₀.₅Fe₀.₅Al₁.₆Cd₀.₄O₄
- Ni₀.₅Fe₀.₅Al₁.₄Cd₀.₆O₄
- Ni₀.₅Fe₀.₅Al₁.₂Cd₀.₈O₄

2.2.1 Stoichiometric calculations

2.2.1.1 Calculation for Ni₀.₅Fe₀.₅Al₁.₆Cd₀.₄O₄

Calculation for aluminium nitrate solution

Solution of aluminium nitrate for x=0.4 composition having molarity 0.08M was prepared using 100mL solution from 0.2M stock solution of aluminium nitrate and poured in a 250mL measuring flask and then filled with distilled water up to the mark.

Calculation for cadmium nitrate

A : B :: C : D
0.1 : 2 :: y : 0.4
(2) (y) = (0.1) (0.4)
y = (0.1) (0.4)/2
y = 0.02M

A = 0.1M of Al(NO₃)₃ used, B = Stoichiometric amount of Al(NO₃)₃
C = Molarity of Cd(NO₃)₂ to be required, D = Stoichiometrically required ratio of Cd(NO₃)₂
1000mL water contains amount of Cd(NO₃)₂ = 308.50g
1mL water contains amount of Cd(NO₃)₂ = (308.50/1000) = 0.3085g
250mL water contains amount of Cd(NO₃)₂ = (308.50/1000) x (250) = 77.125g
0.02M Cd(NO₃)₂ solution = (77.125) x (0.02) = 1.5425g

2.2.1.2 Calculation for Ni₀.₅Fe₀.₅Al₁.₈Cd₀.₂O₄

Calculation for aluminium nitrate solution

Solution of aluminium nitrate for x=0.4 composition having molarity 0.08M was prepared using 100mL solution from 0.2M stock solution of aluminium nitrate and poured in a 250mL measuring flask and then filled with distilled water up to the mark.

Calculation for cadmium nitrate

A : B :: C : D
0.1 : 2 :: y : 0.2
(2) (y) = (0.1) (0.2)
y = (0.1) (0.2)/2
y = 0.01M

A = 0.1M of Al(NO₃)₃ used, B = Stoichiometric amount of Al(NO₃)₃
C = Molarity of Cd(NO₃)₂ to be required, D = Stoichiometrically required ratio of Cd(NO₃)₂
1000mL water contains amount of Cd(NO₃)₂ = 308.50g
1mL water contains amount of Cd(NO₃)₂ = (308.50/1000) = 0.3085g
250mL water contains amount of Cd(NO₃)₂ = (308.50/1000) x (250) = 77.125g
0.01M Cd(NO₃)₂ solution = (77.125) x (0.01) = 0.77125g

2.2.1.3 Calculation for Ni₀.₅Fe₀.₅Al₁.₄Cd₀.₆O₄

Calculation for aluminium nitrate solution

Solution of aluminium nitrate for x=0.6 composition with molarity 0.07 was prepared
using 87.5mL solution from 0.2M stock solution of aluminium nitrate in a 250mL measuring flask.

Calculation for Cd(NO₃)₂

\[ A : B : C : D \]
\[ 0.1 : 2 : y : 0.6 \]
\[ \text{(2)} \ y = (0.1) (0.6) \]
\[ y = (0.1) (0.6)/2 \]
\[ y = 0.03M \]

\[ A = 0.1M \text{ of Al (NO₃)₃ used, B = Stoichiometric amount of Al(NO₃)₃} \]
\[ C = \text{Molarity of Cd(NO₃)₂ to be required, D = Stoichiometrically required ratio of Cd(NO₃)₂} \]
\[ 1000\text{mL water contains amount of Cd(NO₃)₂} = 308.50 \text{ g} \]
\[ 1\text{mL water contains amount of Cd(NO₃)₂} = 308.50/1000 \]
\[ 250\text{mL water contains amount of Cd(NO₃)₂} = 308.50/1000 \times 250 = 77.125g \]
\[ 0.03M \text{ solution contains amount of Cd(NO₃)₂} = (77.125) \times (0.03) = 2.31375g \]

2.2.1.4 Calculation for Ni₀.₅ Fe₀.₅ Al₁₂ Cd₉.₈ O₄ Solution of aluminium nitrate solution

Calculation for aluminium nitrate solution

Solution of aluminium nitrate for X=0.8, with molarity 0.6 was prepared using 75mL from 0.2M stock solution of aluminium nitrate in a 250mL measuring flask.

Calculation for Cd(NO₃)₂

\[ A: B::C:D \]
\[ 0.1 : 2::y : 0.8 \]
\[ (2) \ y = (0.1) (0.8) \]
\[ y = (0.1) (0.8)/2 \]
\[ y = 0.04M \]

\[ A = 0.1M \text{ of Al (NO₃)₃ used} \]
\[ B = \text{Stoichiometric amount of Al(NO₃)₃} \]
\[ C = \text{Molarity of Cd (NO₃)₂ to be required} \]
\[ D = \text{Stoichiometrically required ratio of Cd(NO₃)₂} \]
\[ 1000\text{mL water contains amount of Cd(NO₃)₂} = 308.50 \text{ g} \]
\[ 1\text{mL water contains amount of Cd(NO₃)₂} = 308.50/1000 \]
\[ 250\text{mL water contains amount of Cd(NO₃)₂} = 308.50/1000 \times 250 = 77.125g \]
\[ 0.04M \text{ water contains amount of Cd(NO₃)₂} = (77.125) \times (0.04) = 3.085g \]

The above calculated amount of Cd(NO₃)₂ was added with nickel nitrate, iron nitrate & aluminium nitrate mixture. Stirring was done continuously to from a homogenous mixture before adding the precipitating agent. Cd(NO₃)₂ was added in five compositions gradually raised as \( x = 0.0, 0.2, 0.4, 0.6, 0.8 \)

### 2.2.2 Solution Mixing

0.025M Solution of nickel nitrate (in measuring flask of 250mL) and 0.025M solution of iron (III) nitrate (in measuring flask of 250mL) and 0.2M solution of aluminium nitrate (in measuring flask of 250mL) were mixed in a 1000mL beaker. Solution was continuously stirred for about 5 minutes to get homogeneity. pH of the resultant solution came out to be 3 (checked by a pH meter). For synthesis of cadmium doped nickel-iron-nano-aluminates, 0.025M solution of nickel nitrate, 0.025M solution of iron (III) nitrate, 0.2M solution of aluminium nitrate and cadmium nitrate solution of composition \( x = 0.2, 0.4, 0.6, 0.8 \) in sequence were poured in every 1000mL beakers. When cadmium nitrate was mixed in the solution, solution turns to be Brownish.

### 2.2.3 Co-precipitation

After mixing of solution and stirring for about 5 minutes, precipitation was carried out by drop wise addition of ammonium hydroxide as a precipitating agent. Ammonium hydroxide was added with continuous stirring for 3 hours until the pH became 11. Finally, precipitates were obtained in the form of hydroxide after stirring of 3 hours. Reaction of ammonium hydroxide with aluminium nitrate and iron nitrate resulted formation of respective hydroxides at room temperature.

\[ 3\text{NH}_₄\text{OH} + \text{Al(NO₃)₃} \rightarrow \text{Al(OH)}₃ + 3\text{NH}_₄\text{NO₃} \]
\[ 2\text{NH}_₄\text{OH} + \text{Ni(NO₃)₂} \rightarrow \text{Ni(OH)}₂ + 2\text{NH}_₄\text{NO₃} \]
\[ 3\text{NH}_₄\text{OH} + \text{Fe(NO₃)₃} \rightarrow \text{Fe(OH)}₃ + 3\text{NH}_₄\text{NO₃} \]

### 2.2.4 Washing

After stirring, the solutions were kept for about 12 hours until all precipitates were settled. Solution above the precipitates was wasted and precipitates were washed with distilled water many times to get 7 pH. Filtration was not carried out to avoid contamination as well as loss of precipitates after washing was completed.

### 2.2.5 Drying

Precipitates were allowed to settle down after pH=7. They were separated by removing above liquid solution and kept in petri-dish. Precipitates were dried at room temperature and finally kept in oven for 24 hours at 70°C for complete drying.
2.2.6 Grinding

Grinding of dry precipitates was done using a pestle mortar after washing it with detergents to make it free from impurities. Pestle mortar was dried before use. All the samples were weighed on weighing balance after grinding and kept in air tight, labelled sample bottle to avoid contamination.

2.2.7 Annealing

Annealing of sample was carried out by using ceramic crucible. Crucibles were washed and dried properly. After weighing along with their lids, crucibles were labelled at bottom using lead pencil. Sample with amount 1.00g, 1.90g, 1.79g, 1.90g, 1.65g with composition x=0, 0.2, 0.4, 0.6, 0.8 respectively were added in each crucible and placed in a furnace at 700 °C temperature for 6 hours.

After annealing hydroxides were transformed to oxides of various compositions. In the last, samples were characterized by FTIR.

\[
\begin{align*}
4\text{Al(OH)}_3 & \rightarrow 2\text{Al}_2\text{O}_3 + 6\text{H}_2\text{O} \\
4\text{Fe(OH)}_3 & \rightarrow 2\text{Fe}_2\text{O}_3 + 6\text{H}_2\text{O} \\
\text{Ni(OH)}_2 & \rightarrow \text{NiO} + \text{H}_2\text{O}
\end{align*}
\]

3. RESULTS AND DISCUSSION

3.1 SEM Analysis of Nano Ni–Aluminates

A Scanning electron magnifying lens (SEM) is an electron magnifying instrument that checks the outer layer of sample with a focused light emission to get pictures of the material [32]. At the point when electrons contact particles in a sample, they produce an assortment of signs that give data about the sample's surface geography and piece. A picture is made by joining the place of the electron shaft with the power of the identified sign in a raster filter design [32].

The morphology of \((\text{Ni}_{0.5}\text{Fe}_{0.5}\text{Al}_{2}\text{O}_4)\) revealed a consistent pattern in all cases, characterized by visible aggregation of tiny particles. This aggregation was detected at two different magnification levels: 2m and 20m. This behavior is most likely due to nearby particle contact and bonding, which is assisted by hydrogen bonding with water molecules [33]. Capillary action then comes into play during the drying process of the precursors, further improving particle cohesiveness.

3.2 UV-Visible Characterization of Cd Doped Ni-aluminates

The UV-Visible spectra of Cd-doped Nano-Ni-Aluminates \((\text{Ni}_{0.5}\text{Fe}_{0.5}\text{Al}_{2-x}\text{Cd}_x\text{O}_4)\) with varied \(x\) values (0.2, 0.4, 0.6, and 0.8) show the presence of four distinct absorption bands spanning diverse wavelength ranges: 230-370 nm, 350-400 nm, 586-669 nm, and 900-1250 nm. According to existing literature, the absorption peaks at 344 nm and 560 nm relate to charge exchanges between metal and oxygen atoms [34]. The absorption band from 586 to 669 nm is related with \(\text{Ni}^{2+}\) ions in a tetrahedral coordination, whereas the band from 900 to 1250 nm is associated with \(\text{Ni}^{2+}\) ions in an octahedral coordination [35].

Significant modifications are reported in Cd-doped NiAl2O4. Additional absorption bands appear between 430 and 580 nm, with a modest absorption range between 720 and 780 nm and
a larger band stretching from 900 to 1250 nm. These modifications are linked to oxygen and cadmium charge transfer processes in both octahedral and tetrahedral locations. The last two wavelengths are associated with d-d transitions of Cd atoms in octahedral and tetrahedral positions, respectively. The complicated spectra represent nickel and Cd coexistence in these many coordination locations.

Light energy absorption at specific frequencies adds to the color of the material, changing the band gap [36]. The excitation of electrons from anionic to cationic bands causes the band gap to change. When Cd ions are introduced into NiAl₂O₄, a new electronic level is inserted between the valence band of O²⁻ and the conduction band of M²⁺, resulting in a considerable reduction in band gap energy. This decrease is visible, with the energy decreasing from 3.11 eV to 2.63 eV. This effect is most likely caused by the electrical structure of the Cd²⁺ dopant, which induces a defect level within the band gap of the host lattice.

Solution was supported on magnetic hot plate stirrer during whole precipitation aided with continuous string at room temperature. After 6 hours, hydroxides were formed in the form of precipitates owing to ability of metal cations to form coordination compounds with hydroxide anion thus providing respective hydroxides.

3NH₃OH + Al(NO₃)₃ → Al(OH)₃ + 3NH₄NO₃
2NH₃OH + Ni(NO₃)₂ → Ni(OH)₂ + 2NH₄NO₃
3NH₃OH + Fe(NO₃)₃ → Fe(OH)₃ + 3NH₄NO₃

After removing from magnetic hot plate stirrer, solutions were kept for 12 hours until all precipitates were settled. Solution above precipitates was discarded and precipitates were separated and washed with deionized water until the pH was dropped to 7 to avoid any acidic or basis impurity. Precipitates were kept in Petri-dish and first dried in open air and finally placed in oven overnight at 70°C temperature. Drying is greatly depend on chemistry of metal ion being used and material properties change with change in pH [39] while 11-12 pH was estimated to be ideal for hydroxide precipitate formation [40] because nuclei coagulate together at this isoelectric point. By increasing pH, the powder float on the surface instead of settling down.

Solution was supported on magnetic hot plate stirrer during whole precipitation aided with continuous string at room temperature. After 6 hours, hydroxides were formed in the form of precipitates owing to ability of metal cations to form coordination compounds with hydroxide anion thus providing respective hydroxides.

3NH₃OH + Al(NO₃)₃ → Al(OH)₃ + 3NH₄NO₃
2NH₃OH + Ni(NO₃)₂ → Ni(OH)₂ + 2NH₄NO₃
3NH₃OH + Fe(NO₃)₃ → Fe(OH)₃ + 3NH₄NO₃

After removing from magnetic hot plate stirrer, solutions were kept for 12 hours until all precipitates were settled. Solution above precipitates was discarded and precipitates were separated and washed with deionized water until the pH was dropped to 7 to avoid any acidic or basis impurity. Precipitates were kept in Petri-dish and first dried in open air and finally placed in oven overnight at 70°C temperature. Drying is preferentially done to allow heat to circulate uniformly for sufficient drying of precipitates.
Table 2. Annealing of Samples

<table>
<thead>
<tr>
<th>Sr no.</th>
<th>Compound composition (x)</th>
<th>Weight before annealing (g)</th>
<th>Weight after annealing (g)</th>
<th>Difference in weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1.00</td>
<td>0.84</td>
<td>0.16</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>1.90</td>
<td>1.53</td>
<td>0.37</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>1.79</td>
<td>1.60</td>
<td>0.19</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>1.90</td>
<td>1.68</td>
<td>0.22</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>1.65</td>
<td>1.24</td>
<td>0.41</td>
</tr>
</tbody>
</table>

sample powder, was observed when sample is weighed again after annealing. Hydroxides were converted into oxide with specific composition because of sufficiently high temperature treatment. Conversion of hydroxide into oxides disclosed some bond breaking, bond shifting and formation of some new bonds. As the rates of dissolution and precipitation are very slow at room temperature so annealing was done at sufficiently high temperature above boiling point to specific extent. Following oxides are expected to be formed during annealing at 700 °C for six hours.

\[
2\text{Al(OH)}_3 \rightarrow \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} \\
2\text{Fe(OH)}_3 \rightarrow \text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O} \\
\text{Ni(OH)}_2 \rightarrow \text{NiO} + \text{H}_2\text{O}
\]

Weight loss was observed owing to water removal during annealing as given in above Table 2.

These oxides were subjected to grinding again to obtain fine aluminates nanoparticles. A slight color change was observed as hydroxides (rust color) were converted to respective oxides. Oxides of nickel and iron react with aluminium oxide to produce aluminates [41]. The obtained fine powder was filled in labeled air tight sample bottles and kept safe for FTIR.

FTIR analysis provides information about bonding and molecular structure. FTIR spectrum ranges from 400-4000 cm\(^{-1}\) and used to analyze and identify nature of prepared nanocrystalline spinel [42]. This technique was used to characterized nano Ni-aluminates and Cd doped nano Ni-aluminates. Both annealed and unannealed samples were used to carry out FTIR analysis. FTIR spectra of Ni\(_{0.5}\)Fe\(_{0.5}\)Al\(_2\)O\(_4\) and Ni\(_{0.5}\)Fe\(_{0.5}\)Al\(_2-x\)Cd\(_x\)O\(_4\) with different compositions (x = 0.2, 0.4, 0.6, 0.8) before and after annealing are shown in Figs. 3 (a – j). FTIR spectrum for each unannealed sample of Ni\(_{0.5}\)Fe\(_{0.5}\)Al\(_2\)O\(_4\) and Ni\(_{0.5}\)Fe\(_{0.5}\)Al\(_2-x\)Cd\(_x\)O\(_4\) exhibit a broad band near 3450 cm\(^{-1}\) due to –OH stretching vibration of free hydrogen bonded hydroxyl group and a second typical absorption band at 1620 cm\(^{-1}\) resulting from deforming vibration of water molecules [43]. Spectra for samples after annealing show peaks in the range of 900-450 cm\(^{-1}\) and 850-500 cm\(^{-1}\) showing presence of Al-O and Ni-O bonds respectively thus confirm the formation of metal oxides bonds [44] and no peak was observed for –OH bond. A peak around 420 cm\(^{-1}\) is assigned to Cd-O bond [45].

Fig. 3. (a) FTIR Image of undoped Ni\(_{0.5}\)Fe\(_{0.5}\)Al\(_2\)O\(_4\) (unannealed)
Fig. 3. (b) FTIR Image of doped Ni$_{0.5}$Fe$_{0.5}$Al$_{1.8}$Cd$_{0.2}$O$_4$ (unannealed)

Fig. 3. (c) FTIR Image of doped Ni$_{0.5}$Fe$_{0.5}$Al$_{1.6}$Cd$_{0.4}$O$_4$ (unannealed)

Fig. 3. (d) FTIR Image of doped Ni$_{0.5}$Fe$_{0.5}$Al$_{1.4}$Cd$_{0.6}$O$_4$ (unannealed)

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Fig. 3. (e) FTIR Image of undoped Ni$_{0.5}$Fe$_{0.5}$Al$_{1.2}$Cd$_{0.8}$O$_4$ (unannealed)

Fig. 3. (f) FTIR Image of undoped Ni$_{0.5}$Fe$_{0.5}$Al$_2$O$_4$ (annealed)

Fig. 3. (g) FTIR Image of doped Ni$_{0.5}$Fe$_{0.5}$Al$_{1.8}$Cd$_{0.2}$O$_4$ (annealed)
Fig. 3. (h) FTIR Image of doped Ni$_{0.5}$Fe$_{0.5}$Al$_{1.6}$Cd$_{0.4}$O$_4$ (annealed)

Fig. 3. (i) FTIR Image of doped Ni$_{0.5}$Fe$_{0.5}$Al$_{1.4}$Cd$_{0.6}$O$_4$ (annealed)
4. CONCLUSION

Coprecipitation method was used to synthesize nano Ni-aluminates and cadmium doped nano Ni-aluminates. Ammonium hydroxide solution was used as precipitating agent. FTIR spectrum for each unannealed sample of Ni$_{0.5}$Fe$_{0.5}$Al$_{2-x}$Cd$_x$O$_4$ exhibit a broad band near 3450 cm$^{-1}$ due to –OH stretching vibration of free hydrogen bonded hydroxyl group and a second typical absorption band at 1620 cm$^{-1}$ resulting from deformative vibration of water molecules.

Spectra for samples after annealing show peaks in the range of 900-450 cm$^{-1}$ and 850-500 cm$^{-1}$ showing presence of Al-O and Ni-O bonds respectively thus confirm the formation of metal oxides bonds while no peak was observed for –OH bond. A peak around 420 cm$^{-1}$ is assigned to Cd-O bond.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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